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ABSTRACT

The quality of redundancy in language usage can be examined to determine its effect on communication efficiency. Semiotic redundancy, defined as the quantity of prolixity between semantic and pragmatic information, has the potential of reducing equivocation and error and, at the optimal level, provides maximum communication efficiency. Thus, redundancy in communication interchanges, when joined with redundancy in the human memory, holds the key to information transfer between people. Research into the semantics, syntactics, and pragmatics of information interchange yields the optimum level of redundancy for truly efficient communication. (CH)

ON REDUNDANCY

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ABSTRACT

A thorough examination of redundancy in terms of its theoretical background, functions, meaning, and classification in relation to language and communication is reported in this paper. Redundancy was classified in accordance with the semiotic dimensions of syntactics, semantics, and pragmatics, and explored on the basis of semiotic redundancy, process-memory redundancy and between-channel redundancy. Semiotic redundancy was defined as the redundancy between semantic and pragmatic information; process-memory redundancy as the redundancy between the information that was being processed and the information prestored in the central nervous system; and between-channel redundancy as the joint information between any two channels.

Discussion focussed upon (1) the functions and drawbacks of redundancy in reducing equivocation and error; (2) the derivation of between-channel redundancy and semantic redundancy; (3) the theorization of process-memory redundancy, semiotic redundancy, and dimensional redundancy and other forms of redundancy; (4) the optimal level of redundancy, subject to the noise and environmental conditions and individual subjects, so as to achieve maximized communication efficiency. Contention was made that process-memory redundancy and semiotic redundancy hold the key to human communication, and hence, warrant further systematic work.

A THEORETICAL EXPLORATION OF REDUNDANCY IN HUMAN COMMUNICATION

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Men are immersed in a sea of information; this is why "man has invented dramatically effective codes for handling information" (Gerard, 1962, p. 4). The effective coding is for effective use and control of information. Effective coding and use of information imperatively requires systematic rules; rules imply constraint. Wherever there is constraint upon any phenomenon, event, system or language, such as the orbit of planets, the color of flowers, the computer system, and any written or spoken language, there are laws. Lawfulness indicates order, particularly in human communication. Hence, constraint is the prerequisite of any law, and "every natural law is a constraint," which infers predictability (Ashby, 1956, p. 130).

Communication is concerned with "human relatedness" (Ruesch and Bateson, 1951). Human relatedness implicitly refers to rules of communication systems, subscribed to by members of any given community. Without grammatic rules, for example, language would be simply chaotic and incomprehensible. Rules imply constraint, and every constraint constitutes redundancy, and for Ashby (1956) constraint is in fact redundancy. Manipulation of redundancy is fundamental in human communication.

Redundancy has many interpretations. For classical information theorists Shannon, Fano (1949), Cherry, and many others, redundancy is a mathematical concept referring to the proportion of relative entropy. On the other hand, for example, "redundancy ... implies an overdetermination of meaning" (Meier, 1962, p. 123) and "redundancy is the repetition of a signal (Smith, 1966, p. 365) -- the latter is conceivably an oversimplification.

Redundancy in information theory is conventionally defined as one minus the relative entropy (relative information) in the following formula as customarily given:

$$\text{Redundancy} = 1 - (H_{\text{actual}} / H_{\text{maximum}})$$

where relative entropy is the ratio of the actual to the hypothetical maximum entropy, which is derived from the equally probable occurrence of each event, symbol, or unit within a given set. It may be recalled that H_{actual} is the fundamental concept of information theory, i.e., $\underline{H} = \underline{P}_i \log_2 \underline{P}_i$ whereas $H_{max} = \log_2 \underline{N}$. Weaver says, redundancy generally . . . is the fraction of the structure of the message which is determined not by the free choice of the sender, but rather by the accepted statistical rules governing the use of the symbols in question. It is sensibly called redundancy, for this fraction of the message is redundant in something close to the ordinary sense; that is to say, this fraction of the message is unnecessary (hence repetitive or redundant) in the sense that if it were missing the message would still be essentially complete or at least could be completed (Shannon and Weaver, 1949, p. 104).

It would be ideal if redundancy could be eliminated and if information processing with any physical channel maximized to the limit of capacity, thereby minimizing the effort and cost involved in information processing. It is, however, seldom the case, as evidenced in the occurrence of error and equivocation. A redundancy-free system in realit, is possible only if the entire channel system of communication is completely error-free and has an unlimited capacity. A redundancy-free system is entirely feasible and can be worked out precisely in any physical communication system by devising the most efficient code. A series of error-free systems is theoretically possible but practically unrealizable, as exemplified in the error-detecting systems built into the more sophisticated computers. The checking system in a computer (for example, the use of a binary digit to govern six binary digits and check the sum to determine whether an error has been made) is a redundant system. Due to the noise-congested channel system and the error-prone nervous system of man, redundancy in fact proves to be a boon to any communication system connected with a living organism. A computer instruction code may be designed to be redundancy-free, but a telephone conversation is by no means completely error-free. The implication is that there must be redundancy in any human communication system.

If the analogy is to be carried further, then life in general follows a redundant pattern, seeking an equilibrium of about 50 percent redundancy -- an equilibrium between the new (unexpected) and the old (predictable) -- between disorganization and organization. Colby, (1958) argued that "the formulation of value systems is just one aspect of the formulation of redundancy systems," as values provide a kind of programming or a code of conduct for the individual.

Controversial Meanings of Redundancy

"Redundancy is a property of languages, codes and sign systems which arises from a superfluity of rules, and which facilitates communication in spite of all the factors of uncertainty acting against it . . . and redundancy is built into the structural forms of different languages in diverse ways. No general laws exist" (Cherry, 1957, pp.18-19 and 118). Redundancy also exists in a variety of forms in connection with a sign or symbol processed by one or more modalities. But the fact that no study has yet attempted to classify all forms of redundancy may be a major factor contributing to the conflicting findings in communication research. The need for clarification and rigorous definition of the redundancy concept seems to be a matter of primary importance; for not all studies employ identical concepts of redundancy.

For example, as Attneave (1959) has attested, "Bricker's usage of 'redundancy' is somewhat different from mine. I consider 'redundant' the information which various stimulus components share with one another, whereas for Bricker, information in excess of that necessary for the determination of certain specified naming or categorizing response is 'redundant,' p. 85)." Binder and Wolin (1964) have clarified some misconceptions about redundancy. In the discussion of inconsistency with respect to Shannon's sequential association, Garner (1962) equates redundancy with contingent uncertainty in terms of distributional and correlational constraint. Binder and Wolin (1964) in presenting their concepts of univariate, bivariate, multivariate, and Markovian redundancy, seem to be of the opinion that the discrepancy in the redundancy concept arises from the models individual researchers have adopted.

Classification Problems of Redundancy

Redundancy derives from entropy or information; therefore, classification of redundancy is exactly that of entropy. To classify information, it seems necessary and profitable to start from linguistics. As Weaver has pointed out, communication seems to involve problems at three levels: "Level A: How accurately can the symbols of communication be transmitted (The technical problem); Level B: How precisely do the transmitted symbols convey the desired meaning? (The semantic problem); and Level C: How effectively does the received meaning affect conduct in the desired way? (The effectiveness problem) (Shannon and Weaver, 1949)."

. . . . The technical problems are concerned with the accuracy of information transference from sender to receiver, of sets of symbols (written speech), or of a continuously varying signal (telephone or radio transmission of voice or music), or of a continuously varying two dimensional pattern (television), etc. The semantic problems are concerned with the identity, or satisfactorily close approximation, in the interpretation of meaning by the receiver, as compared with the intended meaning of the sender . . . The effectiveness problems are concerned with the success with which the meaning conveyed to the receiver leads to the desired conduct on his part (Shannon and Weaver, 1949, pp. 96-97).

These three levels of communication problems may be traced to the theoretical foundation laid down by Morris (1946), who defined "syntactics" as the inquiry into "the relations of signs to the objects to which the signs are applicable" (Level B problems), and "pragmatics" as the inquiry into "the relation of signs to interpreters" (which is less broad than Weaver's Level C problems). Level C problems apparently include such prevalent problems as attitude change and learning, for after all, learning is a change of information, or "the change in performance, associated with practice . . ." (Hovland, 1951, p. 613).

These levels of linguistic study are included in a general term "semiotics" by Morris (1946). Further pursuance in the history of linguistic study indicates that Morris was probably influenced by Bertrand Russell. Based upon Gestalt psychology, Russell (1927) posed three pre-requisites in linguistic studies: (1) physical occurrence of words; (2) the circumstances that lead to the usage of a given word; and (3) effects of words.

All these levels "concern signs and relations, or rules," and they "have not the nature of separate compartments, but overlap one another . ." (Cherry, 1957, p. 221). Syntactic problems be clearly defined, but not semantic and pragmatic problems which involve meaning. Meaning of a sign must be defined in terms of the psychological reactions of those who use the sign (Stevenson, 1944). Since meaning of a sign or a word, in addition to conventional definition or agreement, involves psychological factors of an individual, the solutions for both Level B and C problems are a delicate process. No study has yet shown the relationships among syntactic, semantic, and pragmatic information in communication processes.

Communication from a cybernetist's point of view is to seek the reduction of entropy, or as Norbert Wiener says, "to achieve specific antientropic ends" (Wiener, 1954, p. 48). In any communication, meaning, a loosely defined word and concept, is always present. Because of it, both encoding and decoding processes are deterministic, determined by common usage, rules, and conventions -- all of which are constraint. It can also be safely assumed that the transformation of events into signs in the encoding process is a process of entropy reduction. Entropy reduction implies redundancy. In the decoding process, a reversal of the encoding process takes place; the receiver concocts his meaning based upon signs or signals transmitted by the sender.

Following this line of reasoning, it seems that there are three kinds of information. syntactic, semantic, and pragmatic, involved in any communication. There must also be three kinds of redundancy. However, information theory is based on the statistical probability of the occurrence of signs which, in accordance with experiments by Shannon and other information theorists, is entirely within the realm of syntactics. Once any researcher ventures into the domain of semantics and pragmatics, all kinds of unexpected difficulties emerge. Judging from existing studies, it may be safe to assume that there is a lack of any precise measurement of semantic information. The Bar-Hillel (1955) information model of semantic content working strictly within a theoretical model offers no practical assistance to the solution of the quantification of semantic information. The semantic differential (Osgood, et al, 1957) measures the connotative dimensions of concepts, rather than the amount of semantic information of a whole communication. Wiener (1948, 1954) expounded the measurability of meaning but no methodology has been developed. It seems an unfruitful search for the quantification of semantic and pragmatic information based on information theory.

Semantic and pragmatic information, it seems, would likely remain two formidable topics in communication research. An attempt is made to explore semantic and pragmatic information and redundancy later on. Both semantics and pragmatics are recognized by Carnap (1955) as the two fundamental forms of meaning. One of the realistic approaches to the meaning problem in general and the redundancy problem in particular is to begin by specifying all identifiable sources of redundancy.

Redundancy emerges in many forms. Based upon the conventional redundancy concept and the redundancy formula, some basic forms of redundancy relevant to this study have been or are yet to be identified:

Between-channel redundancy (BCR) -- the redundancy rate of information between channels, usually the visual and the auditory channels.

Dimensional redundancy (DMR) -- the redundancy rate between information dimensions, for example, both loudness and pitch if designated to represent the same information or response, or a word such as "taxicab."

Distributional redundancy (DTR) -- the redundancy rate obtained from the distributional information based upon the frequency of occurrence of every element within a sign system.

Sequential redundancy (SR) -- the redundancy rate obtained from the conditional information which, for example, in a two-letter message, is the dependence of the occurrence of one letter upon the other.

Process-memory redundancy (PMR) -- the redundancy rate between information within the memory system and information being processed.

Semiotic redundancy (SMR) -- the redundancy rate between semantic and pragmatic information.

DTR and SR are sometimes called content-redundancy or structural redundancy or within-channel redundancy. BCR has been empirically explored (Hsia, 1968 b, 1970), but PMR and SMR have not; therefore, both PMR and SMR will be treated more thoroughly in this paper.

Language Constraint as Redundancy

The simple redundancy in the form of repetition is as Cherry (1957, p. 185) says, an addition. And simple addition is costly; but some ingenious ways can be devised to reduce both cost and satiation. In order to reduce cost, it is essential for communication to have selective repetition, instead of repeating the whole ensemble of signals or signs. The parity check in computer storage is essentially based upon the concept of selective repetition. Selective repetition must be, however, aimed at the maximum efficiency and minimum error possibility, i.e., to reach the optimal repetition level. Take the four binary coded messages "00," "01,""10," and "11" for example: if we intend to use one more bit for selective repetition, the optimum solution will be "000," "110," "101," and "011" on even parity check, or "001," "100," "010," and "111" on odd parity check, of which any single error contained would be detected. The even or odd parity check examines whether the sum of the individual bits is even or odd.

In order to reduce satiation, a much better way can be found to introduce redundancy. For example, "taxicab" is a semantically redundant representation of "taxi" or "cab," an easily identifiable redundancy in language. English, which is said to be 50 percent redundant (Shannon and Weaver, 1949,; Goldman, 1953, p. 45) is, to be more exact, about 58 percent redundant (Singh, 1966, p. 20). Redundancy in language may be termed "constraint" (Travers, et al, 1964) in a common sense definition. In a more elegant form, language redundancy or constraint can be differentiated by two major categories: distributional redundancy and sequential redundancy (Garner, 1962, p. 65, pp. 214-220). For the English alphabet, if each letter has an equal chance of occurrence, then we have log 27 = 4.76; however, the actual probabilities for a, b, c, d, e, f, . . . are .082, .014, .028, .038, .131, .029 . . . . Using the standard $H = -\sum P_i \log P_i$ we have 4.129 bits. The relative uncertainty or entropy can be easily obtained 4.129/4.76 = .876. Redundancy is 1 - .876 = .124. This redundancy is distributional redundancy, a quite simple, and easily understood redundancy.

The other language redundancy is sequential redundancy, concerning the certainty of one letter or word dependent upon the previous letter or letters (word or words); i.e., the occurrence of a letter or word is conditional upon letters or words preceding it. By an empirical test of a randomly selected sentence of 129 letters for a subject to guess one letter after another, the average information was found to be 1.93 per letter (Singh, 1966, p. 19). The ratio or relative entropy is then 1.93/4.76 = .405. The sequential redundancy is thus .595; consequently the difference between distributional redundancy and sequential redundancy, .471, can be attributed to sequential redundancy alone. One may also calculate the sequential redundancy in accordance with the formulas worked out by Garner (1962, pp. 216-219).

Sequential redundancy may be empirically determined or mathematically derived; neither can be conveniently done. Adopting a simpler concept of constraint, information and redundancy may empirically and heuristically be classified in terms of its degree of constraint, without involving exhaustive calculation to obtain the precise amount of sequential entropy and redundancy. From a practical point of view, obtaining sequential redundancy from a large ensemble of information is prohibitively time-consuming, if not entirely impossible, and its utility value is also doubtful. Sequential redundancy seems to hold the key to effective communication. Without sequential redundancy, no error can be detected in a communication, and no teaching and learning is possible, for there is no way to correct grammar or any thing at all. Sequential redundancy alone warrants continuous systematic investigation.

One of the practical uses of distributional and sequential redundancy is the determination of authorship, topic, structure, and time of composition by letter redundancy in English texts (Paisley, 1966). Similarly, composership, structure and time of composition of music may be determined by using the redundancy principle (Moles, 1968, p. 27-32).

Repetition as Redundancy

The simplest redundancy is of course repetition -- a concept often used but misunderstood, as seen from a mother's instruction to a baby. There are two basic kinds of repetition as redundancy: serial repetition, and repetition by multiple channels (Miller, 1951, pp. 104-105). If a mother tells her baby, "no, no, no," the repetition may contain emphasis or reinforcement, but generally it is serial redundancy, intended to convey the message without any mistake. Provided that she thinks the oral communication is not sufficient, she shakes her head, too, as is generally the case. This is repetition with multiple channels -- gesture as visual signal to convey exactly the same idea as the oral.

Repetition generally has two purposes: first, to avoid possible errors of the communication in transition and in reception, since communication in any channel, human or machine, is subject to noise disturbance; and second, to detect error if it exists. As frequently seen in military orders, such as "Attack at 1700 hours, repeat 1700 hours," the simple repetition as redundancy tends to serve both purposes. Understandably the time of hour has the least redundancy in any language; no mistake in times, dates and figures can be caught unless repeated because no language provides redundancy for them.

Indeed, "the most obvious recipe for reliable transmission in the presence of [omnipresent] noise is repetition of the message a sufficient number of times to ensure reliable reception (Singh, 1966, p. 37);" however, repetition is devoid of any new information, and must take space and/or time; therefore, it is costly in terms of communication economy. Furthermore, continuous repetition eventually leads to sensory and mental satiation. It is likely that any stimuli, when repeated, tends to be associated with the cognitive process by human subjects at first, but that gradually such association is no longer elicitable, or becomes exhausted. As Zielske mentioned, the amount learned might appear to vary directly with the frequency of repetition, but repetition during a shorter interval seemed to have a greater effect (Zielske, 1959). Another function of repetition is to establish multiple traces in the memory, as found by Hintzman and Block (1971); however, facilitation that could be attributed to repetition seemed to be not great (Earhard & Fullerton, 1969). The result was satiation, and possible semantic satiation, the gradual loss of meaning (Amster, 1964), almost a duplication of a much earlier study on semantic saturation (Basette and Warne, 1919). Further repeated communication was not only incapable of evoking reaction or association, but suppressed it (Jakobovits & Lambert, 1964). Worst of all, repetition exhibited as well proactive inhibition effects, though it increased the strength of possible memory traces, in the short term memory (Cermak, 1969).

Satiation of communication association seems to depend upon uncertainty or entropy of communication. An inverse relationship can be said to exist between uncertainty and communication satiation; the greater the uncertainty the less satiation, as seen from a reaction time study to ascertain the positive and negative repetition effects by Umilta, Snyder & Snyder (1972).

Repetition could be made more efficient, as pointed out by Pollack (1958), who compared two message procedures, i.e., repetition and network selection: repetition involved repetition of the exact word; for the network selection procedure, three words were spoken in succession, the final word being the one to be recorded by the listener. For example in the series, "Cargo, Oxcart, and Firefly," each of the succeeding words reduced the final possibility by one half, hence, the three words carry three bits of information. The network selection procedure was found considerably superior to simple repetition. Even when repetition was used, accuracy of perception of words in the presence of noise was better if the successive repetitions were as independent as possible

(Pollack, 1959). An apparently insoluble paradox seems to arise here: since an increase in redundancy is proportional to time and cost, and the processing and utilization of the enormous input information would be made easier if redundancy can be reduced (Barlow, 1959). The solution seems to lie in optimal coding -- the striking of a proper balance between redundancy and cost in time and effort.

Between-Channel Redundancy

Numerous studies have plunged into the controversy over the supposed superiority of the auditory, visual, or audiovisual presentation each to the others. The audiovisual simultaneous presentation involves a theoretical dispute on the interfering and facilitating factors of one channel to the other. But in any dual or multiple channel presentation, there is also information shared by different channels, i.e., redundant information; hence, there is also between-channel redundancy. Between-channel redundancy refers here to the redundancy rate of information between auditory and visual channels. All other redundancy previously mentioned is, in a sense, within-channel redundancy, or content-redundancy. Between-channel redundancy is a discrete source of redundancy, independent of other forms of redundancy.

Between-channel redundancy refers to the similarity of information between two channels; it is a bivariate model. Conceivably, between-channel redundancy is unity when both visual and auditory channels transmit identical information; conversely, it is zero when the visual and auditory channels emit completely different information.

It is fairly certain that other things being equal, mutual facilitation for audiovisual information processing takes place when between-channel redundancy is unity; and interference occurs when it is zero (Hsia, 1968 a, b, 1971). Given the consideration that subjects might be either auditory or visual attender, i.e., they are inclined to be more effective with or preferred information from one channel to the other (Ingersoll & Di Vesta, 1972); then one channel complements the other, such as cuing to facilitate the search tasks (Mudd & McCormick, 1960) or the improvement of the visual signal detectability by a supra-threshold auditory signal (Loveless, Brebner & Hamilton, 1970).

Between channel or bisensory redundancy also improves performance as contrasted to unisensory channel in which BCR is nonexistent, or at least no impairment of performance occurs (Loveless et al, 1970). Many models and theories have been proposed to explain the phenomena and functions of BCR in terms of, among others, the energy-summation model for intersensory facilitation (Nickerson, 1970), or the energy integration model (Bernstein, 1970; Bernstein, Rose & Ashe, 1970) suggesting the added intensities across modalities based upon probability summation but not physiological summation (Loveless, Brebner, & Hamilton, 1970); the former referring to a response resulting from the joint occurrence of stimuli neither of which will produce a response alone, and the latter referring to the probability of detecting the double stimulus is greater than that predicted from probability summation. They may be categorized, for our purpose, as the supplementary function of BCR.

Both supplementary and complementary functions of BCR are supposedly effective and valid only when synchronization of bisensory stimuli of the same class and type is perfect. Any lagging, staggering, and even overlapping of bi-channel stimuli may interfere with orderly information processing.

The redundancy of information processed by both the auditory and visual modalities is easily conceptualized; but its computational and definitional problems seem to be overwhelming. Most studies on BCR depart radically from the information theory model and avoid assessing the rate of redundancy between channels. Many experiments use the word "redundancy" in a common-sense way and interpret the "redundant relation" intuitively.

Chan, Travers, and Van Mondfrans (1965) found that if nonredundant information was presented simultaneously through two channels, the visual channel was more efficient than the auditory channel; but how much "redundant" was not ascertained. That study also substantiated the theory that a color-embellished visual presentation would disrupt the auditory channel more than a black-white visual presentation. Color apparently is of another dimension. Obviously, as dimensionality increases, information increases. Besides, different colors seem to have different values (Mezei, 1958; Tikhomirov, 1962). When dimensionality increases but does not result in any additional information to be learned, the redundancy has, in fact, no value, and has only interference effects.

Generally, BCR refers to the similarity of information between two channels: let us say, auditory and visual. If A and V are the auditory and visual sets of signs, all a's and v's are the elements in the sets, we have:

$$\text{Auditory} = \left\{ a \in A \;\middle|\; a \text{ is the auditory signals} \right\}$$

$$\text{Visual} = \left\{ v \in V \;\middle|\; v \text{ is the visual signs} \right\}$$

Clearly, within each channel, there are a number of signals or signs, i. e.,

$$A = a_i, \quad i = 1, 2, \ldots\ldots\ldots\ldots, m,$$

$$V = v_j, \quad j = 1, 2, \ldots\ldots\ldots\ldots, n,$$

The auditory and visual representations have their information contents as customarily defined in accordance with information theory and probability theory, i.e.,

$$\sum p(a_i) = 1, \qquad \text{and} \qquad \sum p(v_j) = 1,$$

and the amount of information is defined

$$H(A) = -\sum p(a_i) \log p(a_i); \quad \text{auditory information,}$$

$$H(V) = -\sum p(v_j) \log p(v_j); \quad \text{visual information.}$$

Apparently the between-channel redundancy cannot be the sum of the redundancy of the two channels; rather it is based upon the joint information derived from the joint probability. Thus

$$\sum p(a_i, v_j) = 1$$

and the joint information transmitted by both the auditory and visual channels is

$$H(A,V) = -\sum p(a_i, v_j) \log p(a_i, v_j)$$

If A and V are identical, i.e., whenever a_i appears, v_j also occurs, then

$$H'(A,V) = \log m = \log n$$

Following precisely the same logic applied to the syntactic redundancy, between-channel redundancy is thus obtained by the conventional formula

$$R = 1 - \frac{H(A,V)}{H'(A,V)}$$

Process-Memory Redundancy

Studies of human memory, based upon a variety of theories, have inundated many journals in recent years; findings are mostly controversial. Among the few things that have been definitely established is the existence of pre-stored information. Irrespective of whose learning theory one subscribes to, be it Thorndike's, Hull's, Skinner's, Guthrie's, Kohler's, Lewin's, Tolman's or Wertheimer's, one must assume first of all, somewhere in the black box, the existence of stored information. Without going into neural transmission, localization of memory, and neural integration of information, etc., suffice it to presume, for our purpose, that information retrieval is possible because of the pre-existent information in the memory systems. Human behavior is dictated by experience, cognition, and to a certain extent, instinct, all of which can be said to be determined by the prestored information; though whether instinct is solely activated by information retrievable from the memory is a debatable topic. Then it is reasonable to assume that redundancy exists as well between information in the memory (internal information), and external information, that is, information not in the memory. For example, for most Americans the Latin language has a very low redundancy with their memory; Chinese a zero redundancy.

The difficulty level of information processing task -- learning, searching, and even thinking -- is generally determined by the amount of both external and internal entropy information. It is then readily seen that difficulty levels are positively related to entropy and inversely related to redundancy. The manipulation of redundancy, along this line of reasoning, holds the key to information processing, learning, and very probably intelligence as well.

This redundancy, the redundancy between information being processed and information within the memory system, probably the most important of all redundancies, may conveniently be termed Process Memory Redundancy (PMR). PMR is not exactly "internal redundancy," as explained by Brown (1959), "Assuming that when a memory trace is established, it usually has some internal redundancy. In other words, the trace is established with more features than are necessary to represent the information which the trace is required to store." This redundancy, Brown argues, takes up memory storage space, but "the trace system (redundancy) can often supply some of the information lost through decay of an individual trace (p. 734)." PMR is not the redundancy among various kinds of information stored in the memory, nor is it the redundancy between internal information and external information which is infinite; it is simply how redundant the information being processed is in relation to internal information. A high school student who has never been exposed to calculus would have extreme difficulty in solving an integral problem, for the PMR in this particular case is almost zero; however, a college math major who is familiar with calculus would have no difficulty in obtaining its solution; the PMR is high so far as he is concerned.

The increase of PMR, it may be intuitively conceptualized, lessens the difficulty and increases the comprehensibility of a communication, and used in conjunction with internal redundancy, it may ease the canalization in memory, "Canalization is the term used to refer to the fact that last connections are built up in the form of traces of past experience" (Thorne, 1955, p. 313). Assuming the existence of random effects of noise within the nervous system, the protection of information from loss and interference calls for some internal redundancy; but storage economy must be taken into consideration as "sensory information has to be transmitted from place to place in the central nervous system and the reduction of redundancy before this is done would enable the number of internal connecting fibres to be reduced" (Barlow, 1959). Optimal coding is then the most important task in communication.

Some explanation might be in order here: Stored information in the CNS must be organized; organization implies the existence of rules or systems, hence, internal redundancy. When the incoming information has an almost zero PMR rate, it is difficult to integrate with existing information; if it is completely redundant, no integration will take place, either. Therefore, there must exist an optimum rate of PMR. Presumably the optimum PMR is what canalization needs. But the optimal PMR primarily depends upon coding (Garner, 1970) to provide more stimulus features in transmitted information so as to overcome disruption or noise (Bourne & Haygood, 1959).

To further propound the PMR principle, one might recall what Müller said in the nineteenth century: "External agencies can give rise to no kind of sensation which cannot also be produced by internal causes, exciting changes in the condition of nerves" (Müller, 1964, p. 33). Müller is talking about the potentiality of the visual and auditory reception, and the existence of stored information, but we are primarily concerned with the redundancy ratio between the existing information in the central nervous system and the information being fed into it. To a certain extent, PMR is like the psychological and potential similarity Wallach (1958) has expounded. Even in pattern recognition, for example, the identification of simple, incomplete letters of B, C, and O, in what is known as "closure" (Engel, Kollat & Blackwell, 1968, p. 92) utilizes the PMR principle.

How to guess missing letters in a text is one of the applications of the redundancy of letters. In Shannon's "guessing game," the subject is to guess the next letter until the right letter is identified. On the surface, both are based upon sequential redundancy; however, the guessing game and replacement of deleted letters involves PMR. There must be information in the memory for subjects to guess the next letters, or fill out the missing letters and words.

Results of many experiments may be fitted into the PMR concept: the more frequent words have higher thresholds and are therefore more easily processed (Solomon and Howes, 1951); this is true even under noise conditions. Reading rates are faster with more familiar words (Pierce and Karlin, 1957) and the number of repetitions required for correct identification is also affected by word frequency (Postman and Rosenzweig, 1957) as we know very well by now both word frequency and familiarity are associated with PMR.

Experiments using the redundancy principle but not so specified are numerous; for example, the study of "familiarity of letter sequences and tachistoscopic identification" (Miller, Bruner, and Postman, 1954), the results of which show the perception of groups of letters is affected by the degree of resemblance of the groups of letters to ordinary English. All guessing games, replacement of missing letters or words, (for example, McLeod & Anderson, 1966), deletion (DeRosa, 1969), "Taylor's Cloze procedure," paired associate learning and most of verbal learning belong to this category. In fact, all communication tasks contain a certain degree of redundancy. The manipulation of various forms and properties of redundancy, to a great extent, determines the efficiency of communication.

Another implicit form of redundancy is readability. Klare (1963) has compiled nearly forty readability formulas, and discussed their features, and Watkins (1971) has reviewed many readability formulas. All these readability formulas are derived from variations of redundancy or constraint; they could be summarized on the basis redundancy formula, i.e., $\underline{R} = 1 - \underline{H}_{actual} / \underline{H}_{max}$. So far as individual differences such as intelligence or vocabulary are concerned, PMR is involved; the difference can be expressed in terms of prestored information. The rationale for using redundancy as the standard formula for all readability formulas seems quite legitimate, as readability is concerned mainly with distributional information with syllables, phenemes. letters, words, and/or the ratio of any combination of these four. When redundancy is used to replace readability formulas, not only distributional but also sequential redundancy can be known. Thus, ~ ore precise measure of readability can be made available -- one which would not be limited only to a particular language.

Semiotic Redundancy

Communication processes have been diagrammed, flowcharted, and categorized in a variety of ways. Basically, communication involves three levels of problems, as described by Weaver, the "technical, semantic, and effectiveness problems" (Shannon and Weaver, 1949). Morris (1946) has delineated communication problems within a semiotic universe of which there are three aspects or dimensions of communication: syntactic, semantic, and pragmatic. Briefly, syntactics is concerned with relations between signs, basically a technical problem; semantics with relations between signs and their designata, a problem with meaning; and pragmatics with aspects involving sign users, an effectiveness problem (Cherry, 1957, p. 241; Shannon & Weaver, 1963 (1949) p. 4). Syntactic information, obviously, refers to the physical properties transmitted or received, i.e., signs and signals without intrinsic meaning. Meaning or signification is attached to or derived from it in the encoding and decoding processes, both of which are more deterministic than probabilistic, depending on usage, culture and environments. In the encoding processes the encoder transfers the objects, events or thoughts from sources into signs. This involves fundamentally two levels of signification: for our purposes these are defined as intended and expected information. Intended information is the signification the communicator assigns to his transmitted signs, whereas expected information is the signification he expects the receiver to derive from them. In the decoding processes, a reversal of the encoding processes involves also two levels of signification, i.e., interpreted and envisaged. The receiver construes his own interpreted information based upon the syntactic information through whichever medium, and envisages partly or wholly the signification intended by the communicator. The communication processes may be represented by the schematic diagram as follows:

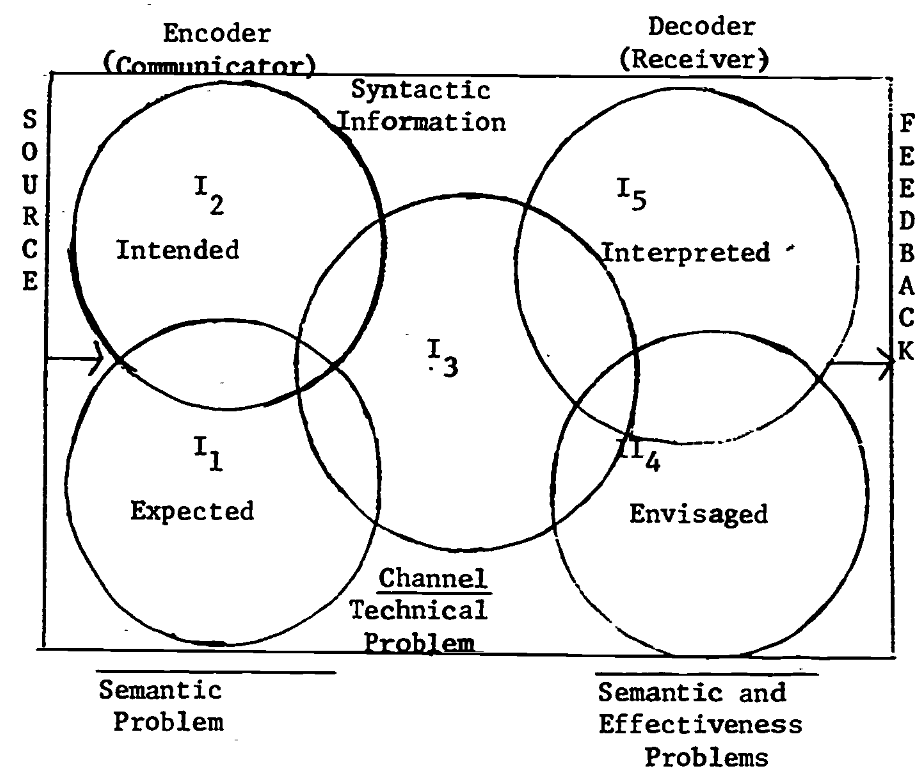

Figure 1 Schematic Diagram of Communication Processes

Letting intended information be I_1, expected information I_2, syntactic information I_3, interpreted information I_4, and envisaged information I_5, in the idealized communication I_1, I_2, I_3, I_4, and I_5 should be identical. The encoder endeavors to make I_1, I_2, and I_3 as similar as possible, and the decoder attempts the same with I_3, I_4, and I_5. The link between the encoder and decoder, as can be readily seen, is nothing more than the syntactic information transmitted and received. Conceivably, the ideal relationship among the five is perfect redundancy; however, only a partial redundancy can be achieved in any real communication situation.

Considering the simplistic example of a child's crying "ma,ma..", syntactically it is nothing more than the word "ma,ma," but it is full of intended and expected information. Only the mother is capable of interpreting it at a given time under a given situation; it may mean a number of things, such as: "I want a toy," "My diaper needs changing," etc. When the mother receives the information, she is not completely free to interpret the meaning of her child's cry. From past experiences (prestored information having probability associated with all possible events, e.g., "the child is hungry," etc.), she immediately forms her interpreted information based upon the envisaged information which is derived from the syntactic information. When these five levels of information are matched, i.e., they share a high degree of redundancy, the child's need is satisfied because his mother correctly interprets his intended and expected communication, and takes appropriate action based on the information received.

A new mother has a world of uncertainty about what the child's cry means; however, from experience by trial and error to relate communication with events; i.e., to establish redundancy, she gradually, perhaps unconsciously, works out a redundancy system in the communication between herself and her child. Only when she becomes an experienced mother, is she able to differentiate communication, based upon her redundancy system. Similarly, the child is also gradually conditioned to discriminate. By a continuous information transition, playing the game of semantics and pragmatics, the child and the mother will make perfect information transference possible. As time goes on, information accumulates in the memory system; thus, more sophisticated information transference is possible. Provided that syntactic information suffers no change in the transaction between transmission and reception, with which most of information theories books (Shannon & Weaver, 1949; Goldman, 1953; Edwards. 1964; Pierce, 1961, among others) dealt, the redundancy between I_1, I_2, and I_3, I_4, is semiotic redundancy. When a Russian told an American about "democracy," the American could hardly believe his ears, and invariably doubted that there could be democracy under a totalitarian regime; likewise, an American could hardly convince a Russian that the U. S. A. is a democratic country under a capitalist system. This may be called semiotic discrepancy -- very low in semiotic redundancy.

Syntactic Redundancy

Syntactic redundancy may be distinguished as falling into two major categories in terms of channel, i.e., within-channel and between-channel redundancy. Under each category, there may be found three major sub-categories: repetitional, distributional and sequential redundancy. Of the repetitional redundancy, further subdivision is possible, for example, immediate repetition, partial repetition, intervalled repetition, delayed repetition, and any combination of the four. Distributional redundancy is what is conventionally called structural redundancy, whereas sequential redundancy is simply correlation redundancy based on the conditional information (See Garner, 1962).

Each repetition of a whole set of symbols or signs may be defined as 1, regardless of its actual content. This definition applies to immediate, intervalled and delayed repetition because each reproduces exactly the same set of symbols or signs; the only variable among these three is time. Immediate repetition is the repetition of each smallest unit within a set, with no intervening time. Intervalled repetition is the breakdown of the whole set into segments which are then repeated. Delayed repetition is the repetition of the whole set of symbols or signs after a time delay of any duration.

When a message is repeated over and over, the repetitional redundancy (but not the within-channel redundancy) is additive, with the restriction of $0 \leq R \leq N$ where N is the number of channels and/or repetitions. However, all other redundancies are still subject to the restriction of $0 \leq R \leq 1$. The approaching of unity by PMR suggests the gradual absorption of information, until there is no more information in the message to be processed or learned. Implicitly, repetition, which we have explored in the previous section, is the least effective redundancy method in learning and communication, when cost in terms of time and effort is taken into consideration.

The obvious strategy of using repetition method as redundancy is to adopt a measure of selective repetition, instead of repeating the whole thing in order to (1) economize time and space needed for the redundant information; (2) attempt to establish the syntactic information with semantic and pragmatic information more easily; in other words, to achieve maximum semiotic redundancy, and (3) provide means for increasing memory strength so as to achieve maximum retention. Understandably, selective repetition must be worked out in view of the difficulty, novelty, associability, and relevancy of the communication appropriate for a systematic study in the examination of immediate, delayed, and intervalled repetition in whole or in part. So much the better if the classes and types of stimuli can also be differentiated in relation to different ages and sexes as well.

More effective use can be found in sequential redundancy, as contrasted to distributive redundancy. Choosing randomly four letters of the alphabet, Miller (1958) set up elaborate strings of letters, and found that learning increased with the degree of redundancy, though the amount of information processed decreased. In a similar study, Hogan (1961) generated strings of symbols of four redundancies 53, 76, 84 and 90 percent respectively, and found that information processing time decreased with the increase of redundancy, slowly at first and rapidly above 76%.

Semantic Redundancy

As syntactic information is more or less stationary, constant, and tangible, it is therefore measurable, and has been expounded since 1949 when Shannon published his book. Such is not the case with semantic information, though Wiener (1954) insists that meaning is measurable and Bar-Hillel and Carnap (1953) actually set up a model to demonstrate that semantic information could be quantified, therefore, is measurable. Since the efforts of these two scholars, no one seems to have attempted the working out of a system to measure the amount of semantic information.

An apparent strategy for appraising semantic information seems to exhaust the significance in all its shades and nuances within a communication message. A starting place, for example, might be the categorization by Ogden and Richards (1923) of the definition of meaning into various unspecified groups. Within each dimension (Ogden and Richard's groups), there are a number of subdivisions of meaning which may be considered variables. Within each variable there may be levels and subdivisions. If necessary, further and finer differentiation is possible. Using Ogden and Richards' example on the meaning of "beauty," the following categorization is attempted:

The Meaning of Beauty

A: a. the simple quality of beauty
   b. a specified form

B: a. an imitation of Nature
   b. a result from successful exploitation of medium

c. the work of genius
d. the revelation of (i) truth, and (ii) the spirit of Nature
e. the ideal
f. the universal
g. the typical
h. the production of illusion
i. leading to desirable social effect
j. an expression

C: a. pleasure
b. emotion
c. a specific emotion
d. involving the processes of empathy
e. vitality
f. synoesthesis

Ogden and Richards have, in their way of classification, listed all possible significations of the word "beauty," but by no means is the meaning of "beauty" exhausted in their list. Nevertheless, the systematic categorization shows that even a very complicated concept such as "beauty" may still be exhaustible in its meaning. The meaning of "beauty" as given by Ogden and Richards may be quantified as follows:

Table 1 Quantification of the Meaning of "Beauty" (as given by Ogden and Richards) with Probability Variables

Semantic Dimension	Probability Variables	Original Definition
D	P	
A	x_1, x_2	a, b
B	$y_1, y_2, \ldots, y_{11}$	a, b, . . ., j
C	$z_1, z_2, \ldots, z_6$	a, b, . . ., f

By using the model of McGill (1954) or Shannon and Weaver (1949), the entropy of the meaning of "beauty" may be worked out. For each variable and dimension the communicator or receiver attaches a different value or weight. The weight can be regarded as the probable occurrence of that variable. Thus semantic information for the word beauty can be obtained by:

$$H(sem) = -\sum p(x_i) \log p(x_i) - \sum p(y_j) \log p(y_j) - \sum p(z_k) \log p(z_k)$$

Considering only the dimensionality of semantic information -- an analogy of changing the amount of information calculated from letters to that of words -- semantic information is then reduced to:

$$H'(sem) = -\sum p(D) \log p\,(D)$$

It can be verified that when only the dimensionality is considered (all elements in a dimension are aggregated into a dimensional total), information is then decreased to a great extent. In the case of an article, message, book, etc., consisting of many different concepts (or essential ideas), each concept can be treated separately from its information content in the same manner. However, it is prohibitive in the tasks of categorization and computation.

Current studies, as contrasted to Morris and Bar-Hillel & Carnap, were concentrated on semantic similarity and its effects of interference and facilitation. Analyzed in conjunction with acoustic similarity, semantic similarity was found to have facilitated total recall (Craik & Levey, 1970), or to have interfered with the judgment on two words with different meanings (Schaeffer & Wallace, 1970 a) and such interference was a function of obligatory memory processes (Schaeffer & Wallace, 1970 b).

Dimensional Redundancy

Dimensionality is another form of redundancy, explored extensively by Garner (1961) and Hsia (1971). Generally, studies of dimensionality were primarily examination of nonverbal or non-language elements such as perception of size, shape, brightness in visual communication, loudness, pitch and duration in auditory communication, degrees of odor in olfactory communication and taste of saltiness in gastronomic communication. They were absolute judgment or discrimination tests; for example, Slak's study (1969) on multidimensional information processing, Biederman and Checkosky's study (1970) on size and brightness.

Dimensionality increases information, but usually not to the sum of information from each and every dimension, despite the fact that its theoretical upper limit is. When dimension increases, particularly when dimensional redundancy is high, dimensionality tends to provide cues or clues so as to facilitate information processing; when dimensional redundancy is low, information increases, and hence information processing difficulty increases as well. So long as the sum of information based upon all dimensions does not exceed the channel capacity, information processing might be easier with the number of dimensions at a decreasing rate (Slak, 1969).

The most difficult task in determining dimensionality lies in semantic relevancy and associability, as contrasted to pure physical properties such as size, shape, and loudness. Generally, when relevancy increases, i.e., dimensional redundancy increases, performance improves; when irrelevancy increases, i.e., dimensional redundancy is low or nonexistent, then information processing suffers.

Conceptually, manipulation of dimensionality of information is the most economic way of increasing information processing efficiency. In practice, however, not too many studies have been designed to tackle this problem, particularly the semantics of languages. Many studies associated stimulus relevancy with redundancy; however, no dimensional redundancy was defined, nor its redundancy rate known. The function of dimensional redundancy seemed similar to other redundancies, for example, in the study of Bourne and Haygood (1959, 1961) dimensional redundancy was found to improve performance and facilitate information processing particularly when irrelevant information increased. Similar findings were reported frequently, for example, studies such as DiVesta and Ingersoll's (1969), and Biederman and Checkosky (1970).

Pragmatic Redundancy

Communication is concerned with pragmatic information toward which all syntactics and semantic information strive to achieve their ultimate objective, provided that we assume all communications were purposive; in other words, pragmatic information is the end product of semantic and syntactic information. Our literature search reveals no mathematical theory on pragmatic information to have been formulated, and studies on "the effectiveness problem" are mostly concerned with attitude change or learning. Carnap and Bar-Hillel (1956) set up a semantic model based upon probability, but the model is hardly applicable to the real world. The pragmatic model of communications, in a broader sense, is an attempt to evaluate "all questions of value or usefulness of a message, all sign recognition and interpretation and all other aspects psychological in character (Cherry, 1957). It is even more than that: pragmatic information includes the mechanism that triggers reaction from the receiver, elicits his response, changes his attitude and opinion, and accumulates information in his central nervous system. The accumulated information is what is loosely called "past experience" or "intelligence." Learning in terms of its terminal purpose of teaching is concerned with pragmatic information, and this is true with any communication in a society; any methodology or theory which could improve pragmatic information processing would result in better communication. This is precisely what Shannon and Weaver (1949) call: "The effectiveness problem of communication." It is readily seen that pragmatic information must consist of both syntactic and semantic information. But the reverse is not true, because pragmatic information is the derivation of syntactic and semantic information; in most cases they are inseparable, but can be described in three different spaces for working out an acceptable model.

Pragmatic redundancy can be obtained by the same procedure as semantic redundancy. When pragmatic information is equal to semantic information, i.e., perfect semiotic redundancy, it is safe to assume that a perfect understanding exists and no errors are possible.

However, such equality in reality seldom exists, because one may be greater or less than the other. Analogous to the equality, it is possible to have both semantic redundancy and pragmatic redundancy equal zero, similar to "GIGO" in computer language; in this case, no understanding is possible. The receiver and the sender have completely different or no ideas at all. This is a special case where no redundancy exists between semantic and pragmatic information in human communications. The difference between semantic and pragmatic redundancy and the lack of semantic-pragmatic redundancy can be assumed as misunderstanding or misconception. When $SR = 0$ and $PR \neq 0$, it is a trivial case, like the response to the Rorschach ink blot. But when $SR \neq 0$ but $PR = 0$, it is simply a case of the sender failing to get the idea across; the communication is destroyed by noise or the meaning lost in transference. Such situations are frequent; no receiver can ever get the communicator's message processed entirely. When $PR > SR$ and neither is 0, in a simple case, it means the communicatee conjures up more than the communicator intends. All implication and inference can be worked out by examining the relationship between semantic and pragmatic information in an attempt to obtain semantic-pragmatic redundancy.

REDUNDANCY FUNCTIONS AND RELATIONS

Over-Redundancy and Under-Redundancy

Except for BCR, redundancy is by no means an alltime boon in communication because of the very likely occurrence of either over-redundancy or under-redundancy in any communication situation. Over-redundancy may be defined as the rate of redundancy in excess of the optimal level, and under-redundancy as that below it. To illustrate over-redundancy, we may ask how many readers would reread the same issue of a newspaper a second or third time? When any communication is processed a number of times, eventually all information is exhausted because of semiotic redundancy and process-memory redundancy. Over-redundancy may be viewed as another form of noise. All effects of noise operate in an over-redundancy situation as well: (1) interfering with new information processing; (2) blocking the channel capacity; (3) reducing the normal processing speed; (4) becoming increasingly boring and bothersome as the over-redundancy rate increases; and (5) depriving an organism of the vital information which is necessary for its survival. In short, too many cooks spoil the stew, and too much redundancy spoils the message, and consequently the reception of the communication. Too much redundancy is as detrimental as zero redundancy in a message.

Under-Redundancy is equally undesirable. There are evidently two cases that need to be considered. First, abbreviation which of itself is nonredundant has to be in some way redundant with the user's memorized information (internal redundancy) and its previous definition. When memory trace cannot be reestablished or memory storage cannot be accessed the abbreviation is in fact noise, and no more redundant presentation of abbreviations will make any difference. Random numbers of nonsense syllables which have zero redundancy work havoc in any information task. In general, redundancy has two opposite functions, working for and against information processing. More accurately speaking, redundancy has two effects, facilitation and deterioration. Only within a certain range is redundancy useful.

Over-redundancy may introduce what is known as "cue conflicts," which affect the subject's certainty (Bruner, 1957). Further evidence can be seen from Baker and Alluisi's study (1962) in which subjects listened to examples of the four types of auditory figures to be practiced making identifications of the corresponding visual figures. They have found that response time to redundancy figures was greater than to random figures, and response time to more complex figures was greater than to the simpler figures.

Generally, appropriate repetition increases redundancy, decreases uncertainty, and facilitates communication so long as repetition still yields new information; of course, the difference between input and output becomes increasingly smaller with each repetition. As more and more information is processed and stored in the central nervous system after each repeated presentation, mere repetition can practically exhaust information as PMR reaches unity, i.e., all the information that has to be processed is already in the memory. By definition, any communication containing no information at all is considered noise, for example, a parrot capable of speaking only a few words would be very much appreciated by someone who heard him for the first time, but not for the hundredth time.

The English language is so redundant that "a fraction of letters can be randomly deleted from a reasonably long message without making the message unintelligible, 'FOR EXMPLE WENTYIVE PRCET OF HE LTTERS I TIS SENTENCE HVE BEN DT RANM.'" (Rapoport, 1965). English prose is still intelligible when all vowels are eliminated, but not when the difficulty level, or the amount of information, is increased, as in this deleted sentence, "probblty a mthmtcl dscpln with ms kn t ths, for xmpl, i gmtry r nlytcl mchncs." This is an example of "under-redundancy." An extreme case of under-redundancy, for instance, is a table of random numbers, which is actually a pure case of zero redundancy. It may be seen that an optimal range of redundancy must be reached to insure intelligibility.

Optimal Redundancy

Optimal redundancy of information is supposed to increase the efficiency in information processing, retention and transfer with the following capabilities: (1) capability of reducing to a tolerable level errors in the encoding process, and checking out errors in the decoding process with its built-in constraint system; (2) capability of reducing the effects of noise, interference and distortion in both the external channel and internal (physiological) channel; and (3) capability of facilitating association and discrimination, establishing memory traces in the organism's central nervous system, and helping to prevent it from forgetting.

These capabilities exist if, and only if, redundancy does not reach the cut-off point beyond which redundant communication gradually reduces information and finally becomes devoid of any information what-soever -- "over-redundancy." There is presumably a critical point beyond which no additional redundancy would ever increase communication efficiency, but would impair it. Optimal redundancy can only be empirically derived, subject to individual PMR. Individual PMR is almost a mysterious concept - on reading an article for the thousandth time, all information is exhausted; however, on listening to Mozart for the thousandth time there is still abundant information that can be associated, interpreted, and therefore, enjoyed.

Generally, we can only attempt to explain the rudimentary concept of optimal redundancy. In a specially designed experiment of spatial signal patterns, the critical point of redundancy has been derived (Hsu 1963). A considerable part of the information contained in a signal structure, Hsu points out, would become "redundant" in the course of frequent repetition of the required operation in association with a definite signal. Three experiments involving naming numbers and pointing to lights in nine-choice tasks with relative stimulus frequencies (Fitts, Peterson and Wolpe, 1963) substantiate Hsu's interpretation. As redundancy increases, average reaction time to the frequent stimulus components increases. The delay in processing time proportionally raises the cost of information processing in terms of decline of information processing capacity at a given time.

Striving toward optimum redundancy as the most effective use of the redundancy concept, many studies varied information relevance, dimensionality, time, and speed, in an attempt to arrive at the optimum loading for the subject so as to achieve maximum information transfer. As a rule, more information can be transmitted by increasing the dimensionality of input information. A study by Anderson and Fitts, replicated by Shinkman (1961) sufficiently demonstrates this concept. When dimensionality increases above the discrimination capacity of the individual, information gain might suffer. Another important factor is time; the length of time is directly proportional to the amount of information. When the information processing time is prolonged, it is similar to lessening the information loading, and in many instances reducing the information complexity and dimensionality, as the information can be differentiated into small segments for easy processing. In studying the effects of repetition and spaced review upon retention of a complex learning task, Reynolds and Glaser (1964) have found that variation in repetition, a simple manipulation of redundancy, has only transitory effects upon retention; but spaced review involved with the time factor produces significant facilitation of retention of the reviewed materials. It must be noted also that spaced review is another form of redundancy.

Departing from counting words and frequencies of the occurrence of input information, many studies have shown a high degree of sophistication in manipulation of redundancy experiments. For instance, Bricker (1955) arranged patterns of lights in a row of five pairs; only one light of each pair could be lit. With three pairs of lights, the maximum uncertainty was 3 bits, but with five pairs of lights the maximum uncertainty increased to 5 bits, although only 3 bits of uncertainty were ever used. Three conditions of varying amounts of information and redundancy were administered. Redundancy in this study definitely shows a detrimental effect upon learning, and the speed of responding: two redundant sets were learned and responded to more slowly even after many trials. The reason is not difficult to understand: the stimulus was flashed at .7 sec., and three pairs of lights could be discriminated perfectly under all response conditions; therefore, redundancy is the undesirable property, taking away information space or time in orderly information processing. Deese (1956) gives statistical backing to his general substantiation of Bricker's findings that the more redundant figures require greater response time. But Deese also finds the complex figures are more accurately identified at the expense of speed. Commenting on these two experiments, Garner (1962) summarized, "The extra discriminability which comes with redundancy is used, given sufficient time, to produce greater accuracy of discrimination, but more time is required to make use of the inherently greater discriminability (p. 191)."

Another pattern discrimination study was conducted by Attneave (1955) who generated a series of patterns by placing dots in a two-dimensional matrix (3 by 4, 4 by 5, or 5 by 7 cells). In the 3 by 4 matrix the dots were always placed randomly; but in the others, they were placed randomly or symmetrically, by mirroring the smaller random matrix. Subjects were asked either to reproduce the patterns or to identify them with a learned label. The symmetrical patterns were identified slightly more accurately than were the random patterns. The result as interpreted by Garner (1962) is that "the increased complexity and discriminability which accompanies increased redundancy does not necessarily aid accuracy of identification." Fitts, et al. (1956, 1957) used various methods of constructing redundant visual patterns, basically of random and constrained forms, from which eight mirroring and repeating patterns were generated. The random figures were discriminated more rapidly than the constrained figures. The differences in discriminating mirroring and repeating patterns were small.

The Relationship of Redundancy to Other Information Properties

As redundancy always increases at the expense of entropy, both entropy and redundancy are required to reach an optimum rate and maintain an optimum ratio if communication is to have maximum efficiency. The rationale for this seems obvious: as redundancy increases, it takes away more and more space which information might otherwise occupy.

Redundancy exists in every language to facilitate information transfer. Regardless of what form it may take, it exists usually at the expense of information and is, in theory, always inversely related to entropy. Its increase invariably brings about a decrease in entropy, and raises the cost of information processing. On the other hand, the increase in redundancy and the correspondent decrease in entropy improves efficiency. The increase in redundancy also curtails the amount of information to be processed, reduces the effects of noise and equivocation, and improves dependability.

Having examined the relations between redundancy and input and between output and input, relations of redundancy to other information properties, notably error, equivocation, and recalled information, become clear. From the fundamental formula for redundancy, it is obvious that redundancy would be unity only when the relative information is zero: actual input information must be zero; consequently equivocation must also be zero. Equivocation maintains a positively linear relation with input beyond the capacity limit; hence it must also be true that equivocation maintains an inverse relation with redundancy when maximum theoretical input remains the same.

The relation of redundancy to output, error, and recalled (joint) information is subject to numerous contaminating factors, chiefly process-memory redundancy, and has not been determined empirically. However, it generally maintains a logarithmic relation with recalled information, error, and output. As the relations between output and input information and between input and redundancy are known, the formulation of the relation of redundancy to other information properties can be worked out. Relative information, the ratio of the actual input to the theoretically maximum input, determines redundancy. Only variation of the actual input in a given communication varies redundancy. Due to the capacity limit and the relation between input and output, the relation between output and redundancy is logarithmic: output and recall information are positively correlated; therefore, the relation of recall information to redundancy is similar to that between output and redundancy. To a lesser degree, this relation is true also between redundancy and error.

The relationship between redundancy and cost is an uncomplicated one. Other things being equal, the actual information processing rate decreases as redundancy increases; therefore cost increases proportionally with redundancy. On the other hand, input information with no redundancy renders information processing extremely difficult, if not impossible. Hence there must exist an optimum relationship between cost and redundancy, which can be found in the optimum ratio between input information and redundancy.

CONCLUSION

The fundamental problem in communication and learning is to achieve maximum communication efficiency. Perfect information transmission and reception (perfect communication) is only theoretically possible; by perfect communication is meant that in which the information being transmitted, processed, and fed back sustains no equivocation or error.

Any purposive communication has an intrinsic objective: it is what Weaver calls "the effectiveness problem" (Shannon, 1949, p. 96). Its prerequisite is, however, "the technical problem," to obtain maximum communication efficiency; the former indicates minimum equivocation (information loss) and the latter signifies minimum error in information transfer from the communicator to receiver. How to arrive at maximum communication efficiency is a crucial matter in the study of communication. In any information transfer, particularly in human communication, principally because of man's limited capacity in information processing together with other physio-psychological limitations, both equivocation and error are inevitable. The inevitability of equivocation and error demands a remedy, and redundancy is probably the most effective means man has found to reduce equivocation and error in communication.

The function of redundancy is to curtail equivocation; to reduce error to a tolerable level in both encoding and decoding processes; to lessen the effects of noise, interference, and distortion; to facilitate information association and discrimination; and to reduce forgetting. But the introduction of redundancy into sign systems and channel systems invariably raises the cost of information processing in terms of time and space, as redundancy has to take away message space that information might otherwise occupy. In order to reduce equivocation and error, it is necessary to increase redundancy; but to increase redundancy is to decrease information. This is the dilemma of communication.

The existence of equivocation and error renders perfect communication impossible. By manipulating redundancy in a message between processing and memory, and between channels, it appears possible to achieve relative maximum information transfer, taking into account entropy, equivocation, error, and redundancy. In other words, information and redundancy must be maintained at an optimal ratio to keep equivocation and error at a relative minimum, and to keep the cost of information processing to a minimum. The maintenance of an optimal ratio between information and redundancy is of fundamental importance in communication and education, for it can increase "selection power." While "selection power" may not be exactly equal to "intellectual power" as Ashby (1956, p. 272) suggests, it may very well be the first step toward achieving maximum communication efficiency.

The key to human communication seems to lie in the determination of the optimal rate of redundancy. It is fairly simple to determine its optimal rate in the syntactic dimension of information on which most information theory studies are focussed. It is still conceptually simple to determine between channel redundancy which is the joint information of any two channels; however, it becomes extremely complex when semiotic redundancy and process-memory redundancy have to be determined. If misunderstanding in human communications is viewed as the result of lack of semiotic redundancy, and difficulty in individual information processing as lack of process-memory redundancy, then it is imperative to study redundancy on a systematic basis in order to determine the precise functions of both semiotic and process-memory redundancy, by exhaustively examining the rate of both redundancies in human communication.

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